



Effect of Increased Respiratory Resistance on Carbon Dioxide Levels and Hemodynamics in the Submerged Exercising Diver

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Background



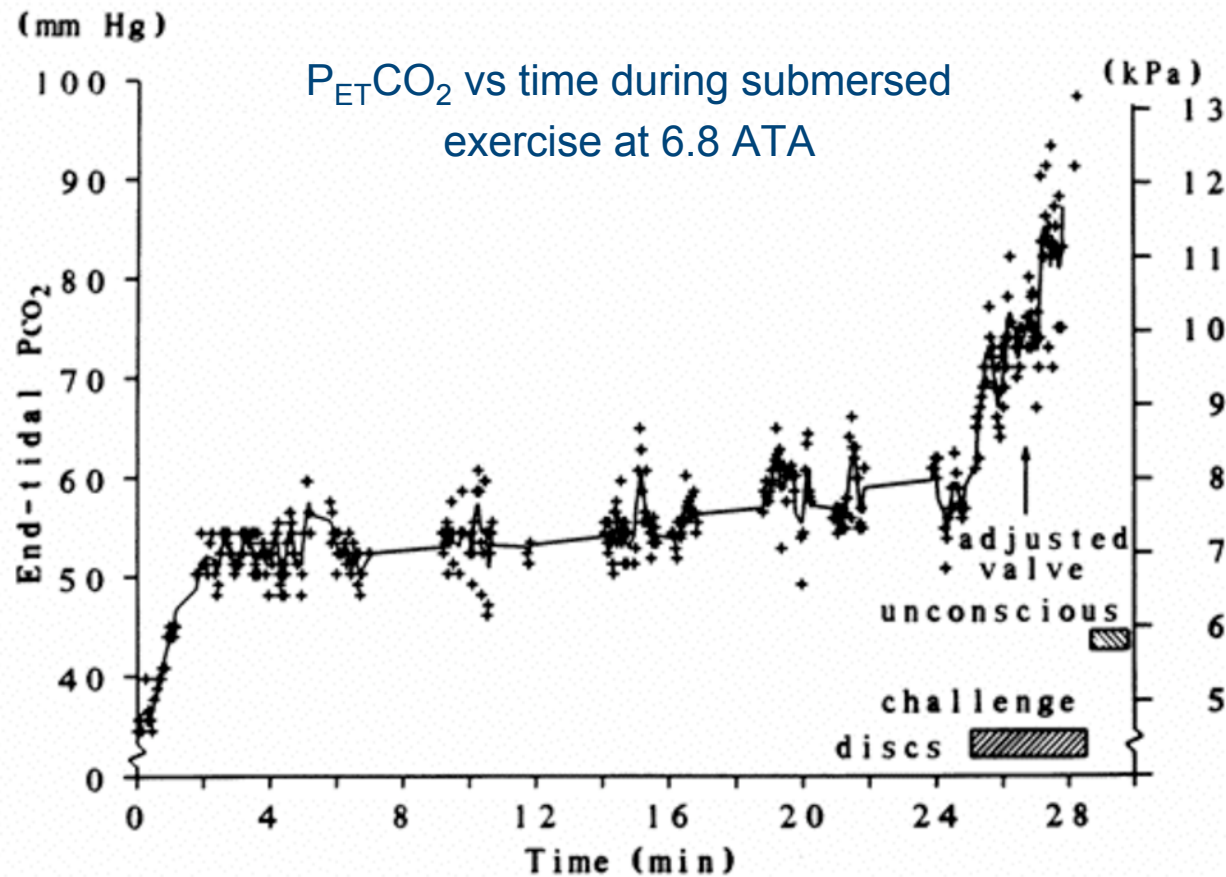
Effects of hypercapnia

- Impaired exercise magnitude and duration
- Increases core cooling rate and decreases shivering threshold¹
- Increased susceptibility to O₂ toxicity and inert gas narcosis
- Confusion
- Loss of consciousness

1. Johnston CE et al. *Aviat Space Environ Med* 67:438-44, 1996.

Background

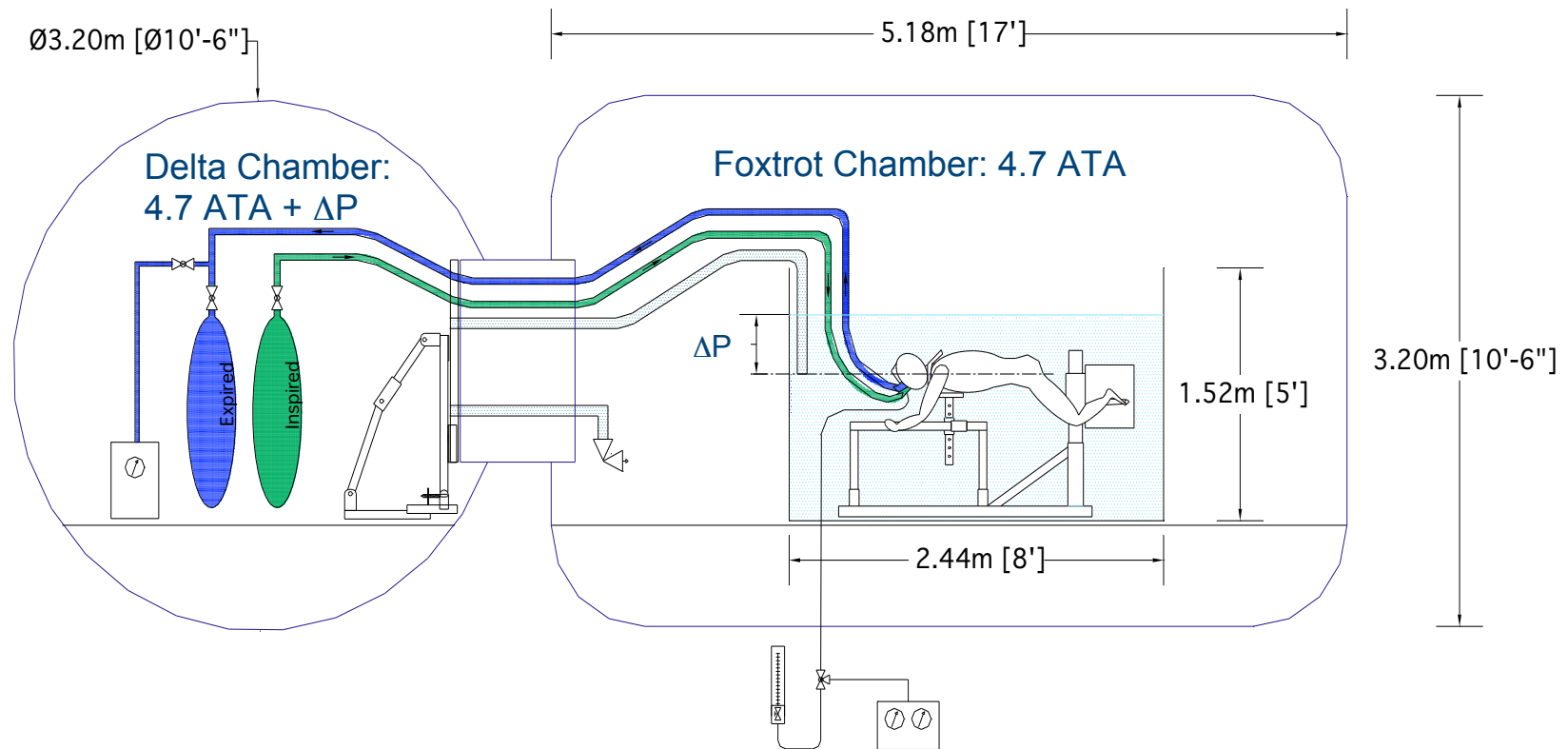
- End-tidal PCO_2 ($P_{\text{ET}}\text{CO}_2$) increases with exercise and external respiratory resistance² during diving



Background

- Arterial PCO_2 (P_aCO_2) is estimated using $\text{P}_{\text{ET}}\text{CO}_2$
- Possible artifacts with $\text{P}_{\text{ET}}\text{CO}_2$
 - Lower than P_aCO_2 with increased deadspace^{3,4}
 - Higher than P_aCO_2 during exercise⁴
- Hemodynamics during diving with external breathing resistance have not been studied
- Hypotheses
 - During exercise at depth, $\text{P}_{\text{ET}}\text{CO}_2$ overestimates P_aCO_2
 - Cardiac output increases due to phasic intrathoracic pressure swings
 - Minute ventilation is decreased with external breathing resistance due to increased work of breathing

Materials and Methods

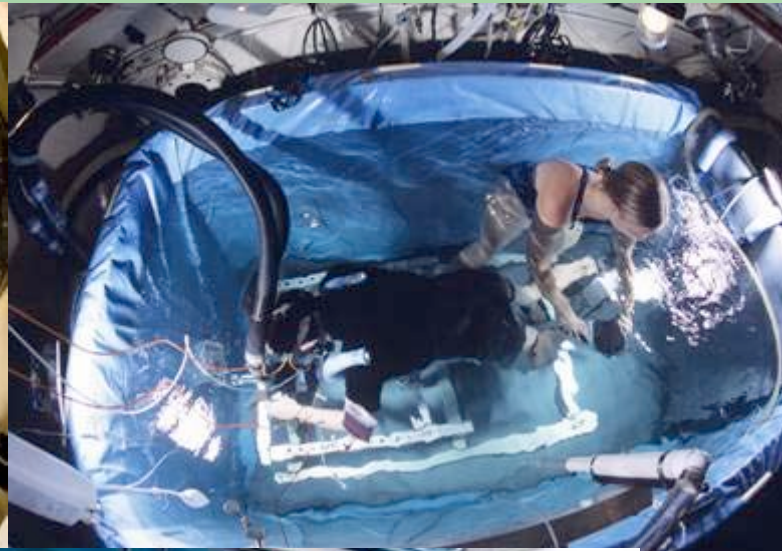


Study setup

Delta Chamber



Foxtrot Chamber

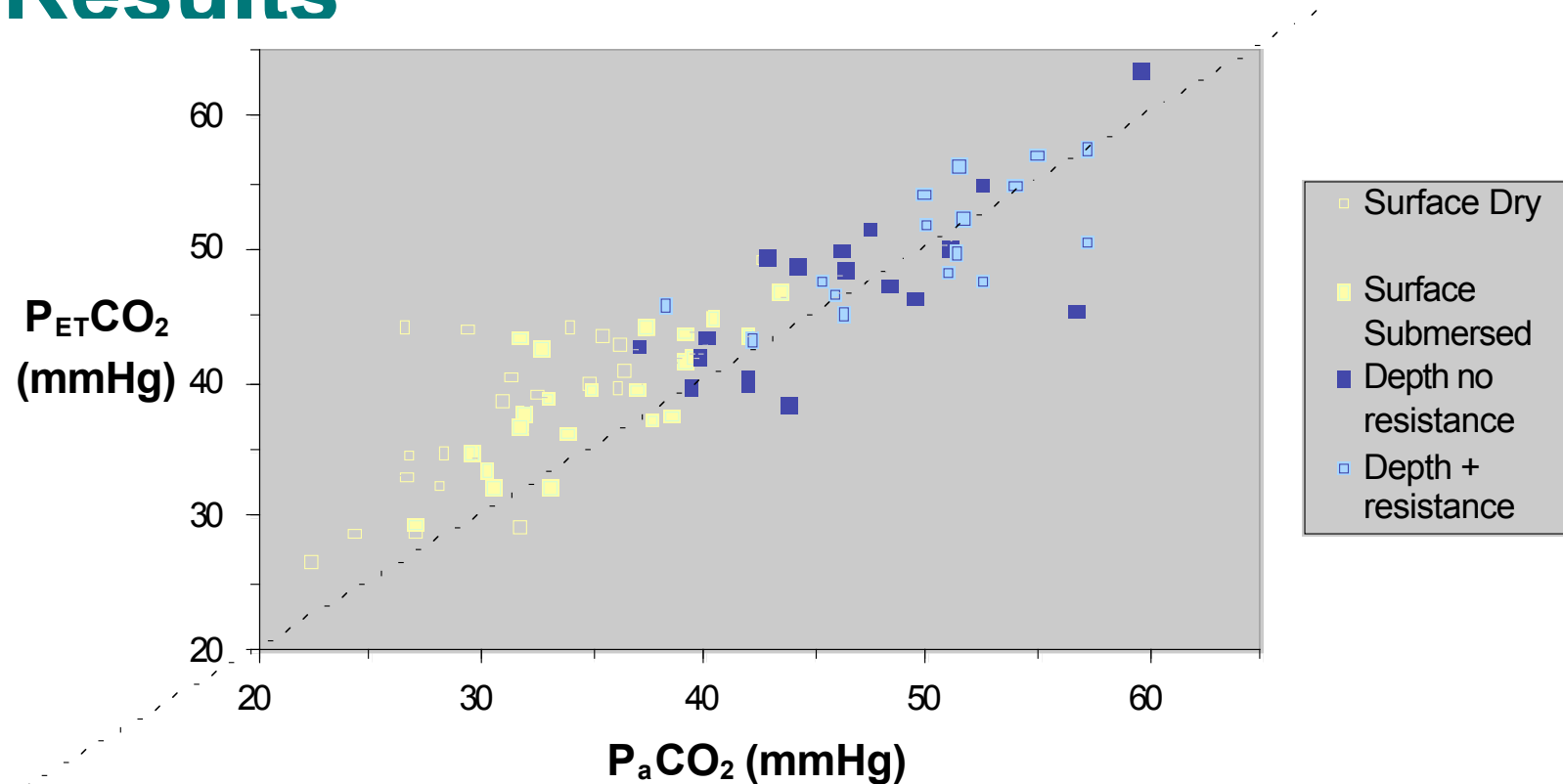


Monitoring and Data Collection

Materials and Methods

- Exercise for each subject
 - Dry and upright on a bike at 1 ata
 - Submerged and prone on ergometer at 1 ata
 - Submerged and prone on ergometer breathing air at 4.7 ata (122 fsw) with low, medium, and high external breathing resistances
- 27 subjects: 8 with external breathing resistance at depth, 19 without added resistance
- Breath-by-breath $P_{ET}CO_2$ and inspired/expired gas concentrations measured using a mass spectrometer
- P_aCO_2 and $P_{\bar{v}}CO_2$ measured by blood gas analysis of arterial blood drawn from a radial artery catheter or mixed venous blood drawn from pulmonary artery catheter

Results

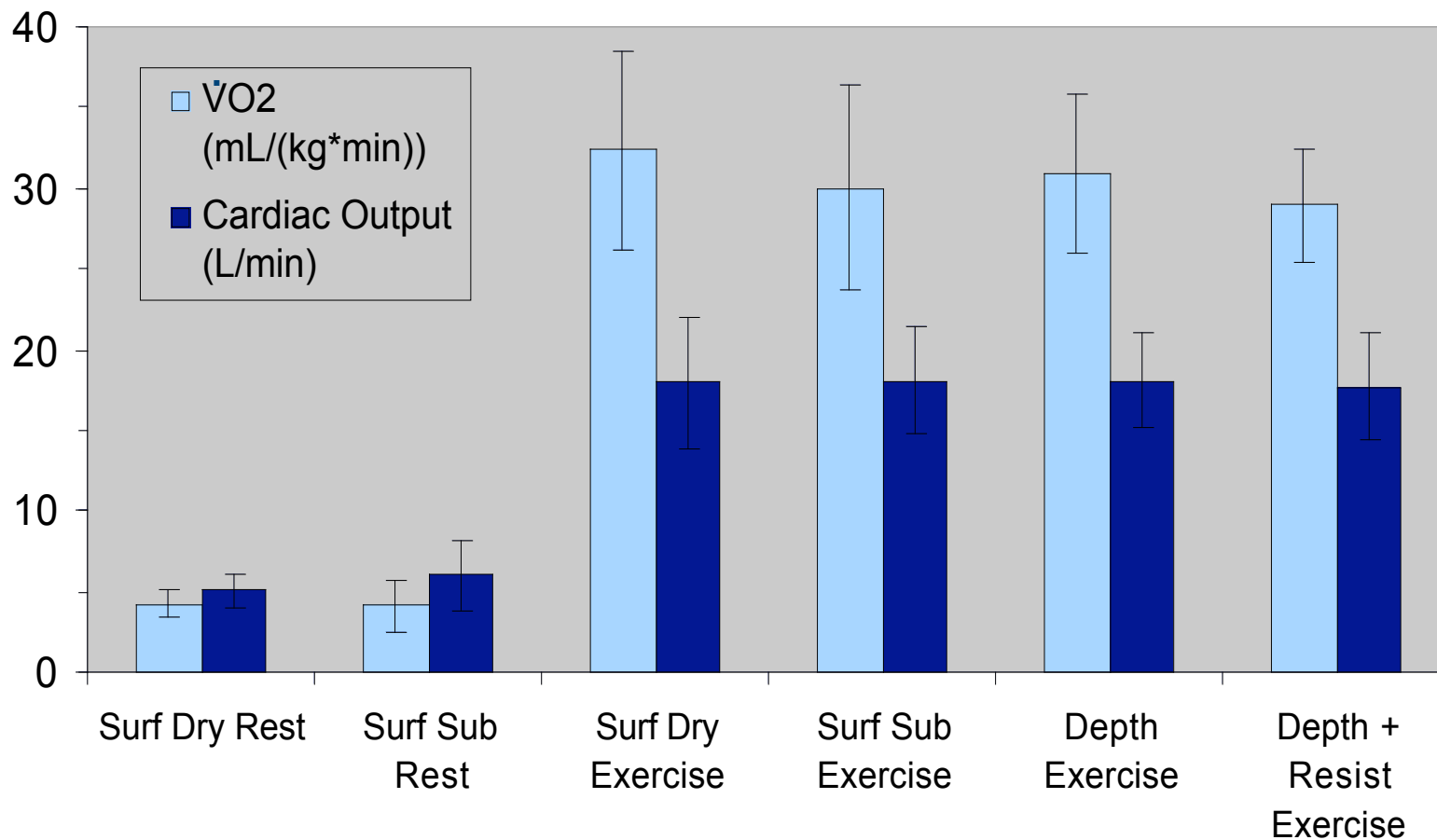


| Condition | P_aCO_2 | $P_{ET}CO_2$ | $P_{ET}CO_2$ vs. P_aCO_2 P Values |
|--------------------------|-----------|--------------|-------------------------------------|
| Surface dry exercise | 31.6±5.2 | 38.0±6.1 | <0.0001 |
| Surface sub exercise | 34.2±4.9 | 38.8±4.7 | <0.0001 |
| Depth exercise no resist | 46.1±5.9 | 46.8±6.2 | 0.66 |
| Depth exercise + resist | 49.3±4.3 | 50.2±5.3 | 0.78 |

All values reported as mean±SD

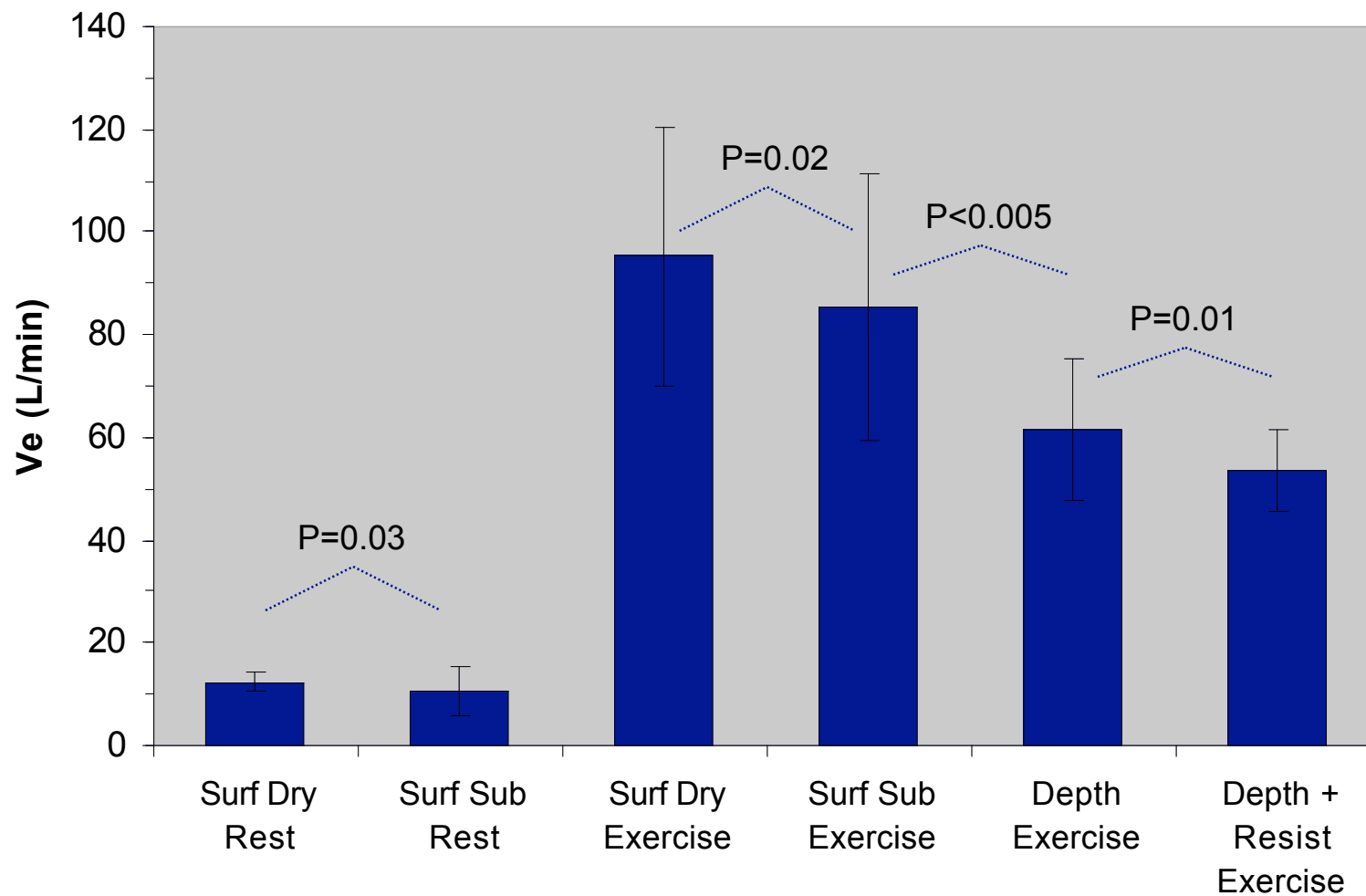
Results

Fick CO and $\dot{V}O_2$ /kg during Rest and Exercise



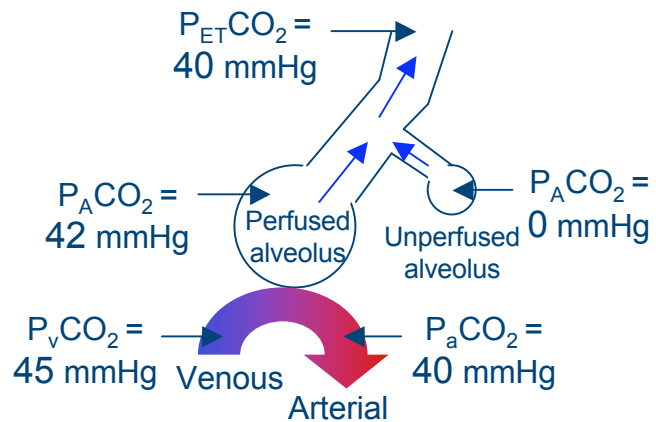
Results

Minute Ventilation during Rest and Exercise

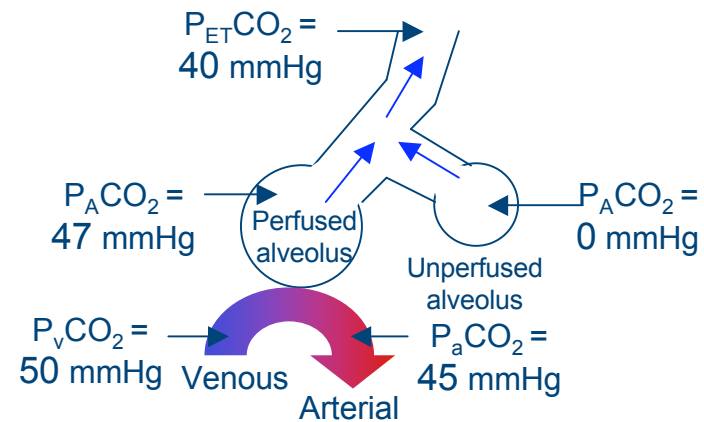


Discussion

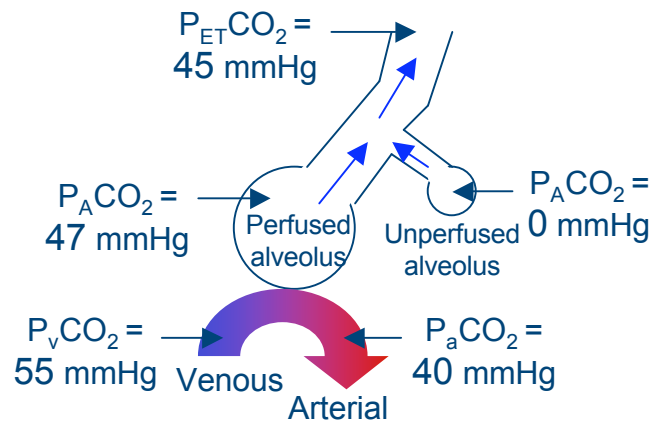
Rest



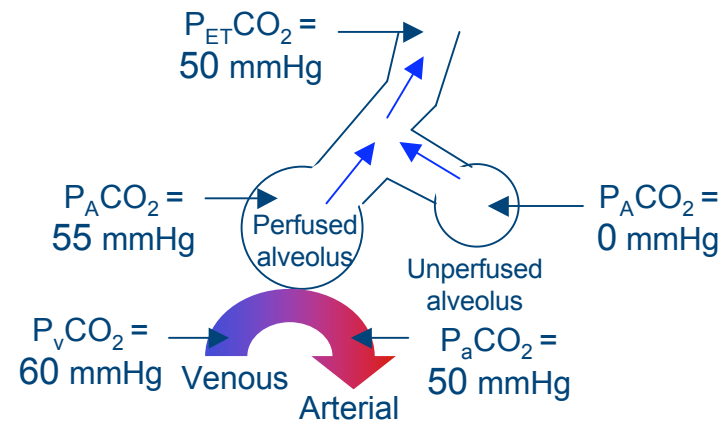
Increased deadspace at depth



Exercise



Exercise with increased deadspace



Conclusions

- At the surface, $P_{ET}CO_2$ is higher than P_aCO_2
- At depth (\pm external resistance), $P_{ET}CO_2$ accurately estimates P_aCO_2
- Cardiac output is unchanged at depth (\pm external resistance) during exercise
- Minute ventilation decreases at depth and with external resistance

Acknowledgment

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